2001-12

An improved inventory control model for the Brazilian Navy Supply System

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Monterey, California

THESIS

AN IMPROVED INVENTORY CONTROL MODEL FOR THE BRAZILIAN NAVY SUPPLY SYSTEM

Artur Luiz Santana Moreira
and
Giancarlo Cuquel

December 2001

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** December 2001	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: An Improved Inventory Control Model For The Brazilian Navy Supply System			**5. FUNDING NUMBERS**
6. AUTHOR(S) Moreira, Artur Luiz Santana and Cuquel, Giancarlo			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**
13. ABSTRACT ***(maximum 200 words)*** Inventory managers in the Brazilian Navy for decades have faced the difficult task of establishing policies and controls to maintain readiness at the highest possible level. The task is difficult because the inventory system contains more than 500,000 items, and many of these items must be procured from overseas. Every year, inventory managers must allocate millions of dollars to buy inventory to support the fleet, and until recently the process has been almost entirely devoid of algorithmic support. We propose a new method for allocating a budget to buy inventory items in the Brazilian Navy. We compare our method with the current one and with an improved version of it. Our results suggest that our method could significantly improve supply readiness in the Brazilian Navy.			
14. SUBJECT TERMS Inventory Management, Forecasting Model, Decision Making Support			**15. NUMBER OF PAGES** 69
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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MASTER OF SCIENCE IN MANAGEMENT

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ABSTRACT

Inventory managers in the Brazilian Navy for decades have faced the difficult task of establishing policies and controls to maintain readiness at the highest possible level. The task is difficult because the inventory system contains more than 500,000 items, and many of these items must be procured from overseas. Every year, inventory managers must allocate millions of dollars to buy inventory to support the fleet, and until recently the process has been almost entirely devoid of algorithmic support. We propose a new method for allocating a budget to buy inventory items in the Brazilian Navy. We compare our method with the current one and with an improved version of it. Our results suggest that our method could significantly improve supply readiness in the Brazilian Navy.

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ACKNOWLEDGMENTS

It is our duty to express our gratitude to the Brazilian Navy for providing us such a great opportunity to pursue a graduate degree in this prestigious institution, the Naval Postgraduate School.

We are beholden to our advisors, Professors Kevin R. Gue and Ira Lewis for their guidance and support for the accomplishment of this thesis.

We thank you also Professor Bill Gates and Commander Kevin Maher that, even though you were not our advisors, always helped us with their experience in the crucial moments of our journey.

We would like also to thank you Captain Edesio Teixeira Lima Junior, whose remarkable ideas inspired the whole concept of this thesis: discovering ways to improve the Brazilian Navy Inventory System.

We would like also to express our special thanks to our parents, brothers and sisters for their love and examples and our families, Claudia and Lucas, and Sandra, for their invaluable support, patience, understanding, and encouragement during the last eighteen months of our lives here in Monterey.

Finally using Psalm 146, we would like to praise the Lord: "Praise the Lord, O my soul. We will praise the Lord all our lives; we will sing praise to our God as long as we live".

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I. INTRODUCTION

A. BACKGROUND

The success of the Brazilian Navy depends on, among other things, an effective logistics system. Logistics tasks such as supply support, transportation and maintenance require sufficient material, personnel, and financial resources, but these are normally scarce in the Brazilian Military Services. [Ref. 1:p. 18] Therefore, it is important that existing resources be used wisely.

Supply support involves receiving, storing, issuing and supplying material for conducting naval operations. The inventory control component of supply support provides a set of policies and controls to monitor levels of inventory and determine what levels should be maintained, when stock should be replenished and how large the orders should be. [Ref. 2:p. 513]

Determining the need for spare parts is extremely complex in a military environment, but especially so for the Brazilian Navy, which has a very diverse weapon systems profile. A significant percentage of the weapon systems was acquired in foreign markets, which makes supply support and inventory control very difficult and expensive. The high cost of support of foreign made weapons systems, which are often bought because of the almost immediate availability, is essentially a “hidden” cost.

The varieties of sources and increasing age of weapon systems have led to a supply system configuration profile that is very complex. Currently, the supply system data base contains more than 50,000 different kinds of equipment, such as radars and engines, 600,000 different items and more than 35,000 different possible suppliers of those items. Most of them are located overseas, which makes it almost impossible to reduce long lead times.

B. INVENTORY CONTROL POLICY

The major goal of the Brazilian Navy inventory control policy is to help maintain a high state of material readiness at minimum cost. Factors that tend to reduce inventory are more accurate forecasts, shorter lead times, improved communication networks, and standardization. [Ref. 3:p. 28] Shorter lead times are difficult to achieve because most suppliers are located far from Brazil and are frequently in North American and European markets. Also, a significant percentage of demand is for obsolete items that are no longer being manufactured. The supply system information system has improved significantly in recent years, but there is still much to do. Standardization will be difficult to achieve as long as the Brazilian Navy's procurement is directed towards foreign weapon systems from different countries. Finally, more accurate forecasts can reduce backorders, because if forecasts are too high there is a tendency to overstock and if forecasts are too low stock outs are more likely.

Because the supply system has only in the past three years achieved some information technology capability, forecasting systems are still in a relatively primitive state. Additionally, most available forecasting techniques require a substantial collection of historical data which many times are nonexistent when major new weapon systems are introduced without the adequate execution of its provisioning.

Because of very limited funding, inventory managers buy mostly spare parts required for scheduled maintenance or overhauls. A small portion of the budget is set aside to cover unexpected demands that occur during normal operations. When an item is required and not available in stock, it must be procured.

Even though the current scenario is not ideal, the Brazilian Navy has been able to support its fleet by using another additional important source of stock. This source is base allowances obtained from the provisioning of new weapon systems.

C. THE NEW APPROACH

In 1999, CCIM, in Portuguese Centro de Controle de Inventario da Marinha, the Brazilian Navy Inventory Control Point (ICP) developed an empirical model called SPAADA – Sistema de Previsão, Análise e Acompanhamento da Demanda, which in Portuguese means "Forecasting, Analysis and Monitoring Demand System" – that is designed to provide a more structured approach to inventory management. The model provides inventory managers with a technical method to invest financial resources while considering inventory parameters such as stock levels, lead times, and patterns of demand, instead of continuing to buy spare parts for overhauls or as a response to unexpected demand. The model is currently in the process of being tested and evaluated. The first tests occurred in 2000 when part of the budget was spent on a sample of 3,000 items that contained more reliable information on their attributes and SPAADA parameters.

D. THE PROBLEM

The problem that this thesis intends to address is stated in the following question: "How effective is the SPAADA model, and is there a superior alternative?"

E. THE SOLUTION AND RESULTS

To address this question, we test SPAADA and two alternative models with sample data from 3,000 items in the Brazilian Navy Supply System. The first alternative model is simply a modified version from the underlying principles of the so-called system approach by Sherbrooke (1998).

The objective of our tests is to see which model generates the fewest backorders when used to spend budgets over a 3 year period.

Our results suggest that the Brazilian Navy's current model could be improved by using either alternative, but the model based on Sherbrooke's work is the best of the three.

In an attempt solve the problem; we develop a model derived from the underlying principles of the so-called system approach developed by Sherbrooke. In this new model, by working with a sample of 3000 items from the Brazilian Navy supply system database and relying on the marginal analysis concept, we will endeavor to minimize expected backorders and, consequently, improve service levels.

Additionally and based on the same sample, we will develop a model that will modify SPAADA by using the concept of genetic algorithms to manipulate the weights assigned to one of its parameters, or the MEG – Material Essentiality Grade, designed to rank the Brazilian Navy supply system database. This model will also minimize the number of backorders and thus improve service levels.

When presenting the results, we will demonstrate that the model based on the concept of marginal analysis achieved better service levels than those achieved by both the original and modified version of SPAADA.

In the next chapter, we present the current model. Chapter III presents the alternatives for improving the current inventory control model. Chapter IV presents the results achieved after the development of the alternatives, and Chapter V presents the summary, conclusions and recommendations of this thesis.

II. THE CURRENT MODEL

A. MODELING ENVIRONMENT

By 1998, the Brazilian Navy had not yet created or adapted an inventory control model from other organizations to address its problems. Poor IT systems and lack of skilled personnel were some of the reasons for not implementing theoretical inventory models available in the literature that could satisfy the Brazilian Navy's needs. These included a reduction in inventory costs and lead times, an increase in service levels and the improvement of readiness.

Consequently, in 1999, the Brazilian Navy decided to develop the SPAADA – Sistema de Previsão, Análise e Acompanhamento da Demanda, in Portuguese, meaning "Forecasting, Analysis and Monitoring Demand System" in an attempt to fill that gap and provide CCIM a decision support tool that could help inventory managers identify the most important items and buy them when needed. SPAADA was also intended to improve support in the planning and acquisition of spare parts. One of the drivers behind the development of the model was the virtually impossible "hands-free" management of the supply system data base that currently has more than 600,000 different items registered, suggesting the need for an automated system that could help inventory managers do their jobs.

The two major objectives of SPAADA are:

- provide the ranking of items in the data base in terms of their importance to the supply system in order to permit inventory managers to focus on the most important items, and
- establish inventory levels and lot sizes for the acquisition of spare parts.

B. RANKING ITEMS

The SPAADA model ranks items based on a weighted sum of seven characteristics. The weighted sum for an item is called its Material Essentiality Grade (MEG).

The comparative concept of SPAADA requires that variance in parameters be reduced in order to not over or under evaluate the MEG of any item. This objective is achieved using grades within predetermined values. For example, items with Demand Frequency equal to 10 or to 100 have the same grade.

SPAADA uses the following parameters and grades:

1. Demand Frequency (DF)

Represents the numbers of times an item was requested in the last four years. The grades for DF are shown in Table 1.

Demand Frequency	**DF < 3**	**3 ≤ DF < 5**	**5 ≤ DF < 10**	**DF ≥ 10**
Grade	2	4	7	9

Table 1. Grades for Demand Frequency.

2. Demand Popularity (DP)

Represents the number of different weapon systems that requested one particular item for the last four years. The grades for DP are shown in Table 2.

Demand Popularity	**DP < 2**	**2 ≤ DP < 4**	**4 ≤ DP < 8**	**DP ≥ 8**
Grade	1	2	6	9

Table 2. Grades for Demand Popularity.

3. Demand Regularity (DR)

Represents how many semesters time one particular item was requested for the last four years. The grades for DR are shown in Table 3.

Demand Regularity	**DR = 1**	**2 ≤ DR < 5**	**DR = 5**	**DR ≥ 5**
Grade	1	2	5	9

Table 3. Grades for Demand Regularity.

4. Navy Popularity (NP)

Represents the number of different weapon systems that have installed this particular item, regardless of its demand frequency. The grades for NP are shown in Table 4.

Navy Popularity	**NP < 5**	**5 £ NP < 10**	**10 £ NP < 15**	**NP ³ 15**
Grade	4	6	7	9

Table 4. Grades for Navy Popularity.

5. Criticality(C)

Represents the importance of the item to the weapon system. The grades established for criticality consider:

- The most important equipment installed in each weapon system to permit the completion of its mission, respecting redundancies (more than one particular equipment able to perform any particular task) and/or alternatives (another equipment able to perform the task, sometimes with some level of deterioration), and
- The importance of the item to the equipment where it is installed.

Each item receives a grade, varying from 1 to 9, based on its influence on equipment performance.

6. Planned Program Requirements (PPR)

Indicates if an item is part of a maintenance list with a higher probability of being demanded by the weapon systems when performing overhauls.

The grades assigned are 0 if the item is not part of any list and 5 if it is.

7. Navy Priority (NPr)

It intends to permit the Navy to emphasize the application of resources to any particular class of weapon systems based on its importance to the Navy mission and/or period of time before its scheduled decommission. Grades vary from 1-9.

Based on these parameters and grades, the Mission Essentiality Grade (MEG) is:

$$MEG = \frac{3DF + 2DP + 3DR + NP + 3C + PPR + 2NPr}{15}.$$

Developers of SPAADA model established the weights based on intuition, rather than formal methods.

C. FORECASTING MODEL AND INVENTORY LEVELS

SPAADA uses exponential smoothing to forecast demand. The model is:

$$F_{t+1} = \alpha A_t + (1 - \alpha) F_t,$$

where

F_{t+1} is the forecast for the next period of observation,

α is a smoothing constant, initially established as 0.5,

A_t is the actual demand of the current period, and

F_t is the forecast for the current period.

Because the Brazilian Navy supply system keeps no lead time data and only limited demand data, SPAADA addresses demand variability with the following estimate for the standard deviation (σ):

$$\sigma = (T^{\gamma} \text{ x } D^{\beta})^{1/2}$$

where

T is the period of time, assumed 8 periods,

D is the actual average demand for the same period, and

γ and β is the constants, both assumed to be equal to 0.7.

Based on the "Empirical Rule", which states that for most data sets roughly two out of every three observations are contained within a distance of one standard deviation around the mean, and roughly 90% to 95% of the observations are contained within a distance of two standard deviations around the mean [Ref. 4:p. 194], SPAADA establishes the safety level as two times the standard deviation (σ).

After having ranked the items, forecasted the necessities and calculated safety levels, the decision regarding budget requirements was established as follows:

$$\text{Budget Requirements} = \sum_{i=1}^{n} [(FD_i + SL_i) \times UP_i]$$

where:

FD_i is the forecasted demand for each item,

SL_i is the safety level for each item, and

UP_i is the unit price for each item.

As the Brazilian Navy is subject to limited funding, the managers must find a way to prioritize budget spending. When SPAADA ranks the items, it provides the necessary management tool to accomplish this task. Basically, the items with the highest MEG will be bought first, for one year supply period, until the budget is exhausted.

SPAADA also considered other inventory levels such as strategic level, re-supply level and maximum level. However, they will not be described as they are outside the scope of this thesis.

D. THE IMPLEMENTATION OF SPAADA

In 2000, the Brazilian Navy decided to partially implement the model to see how the inventory managers would adapt to it. The database was divided and they used SPAADA on a set of 3,000 items. Those items with more reliable attributes and with parameters already assigned were used. This set of items is relatively small comparing to the size of the database because this assignment is a slow, continuous and difficult task. They have to assign grades for each parameter of each item that integrates the Brazilian Navy data base.

Evaluating the quality of the model is also difficult because we cannot compare its outputs to any previous models. (We compare models based on service level - the probability that demand is satisfied immediately from on-hand inventory. [Ref. 5:Vol. I,

p. 93] - and fill rate - the fraction of demand that is filled from on-hand inventory. [Ref. 5:Vol. I, p. 93].) Nevertheless, this set of 3,000 items was ranked using the MEG algorithm and the Brazilian Navy decided to allocate and spend a budget equivalent to 65% of the total budget requirements for these items using the formula described in Section **C**. The acquisition was performed until the budget was exhausted based on the rank provided by the MEG algorithm.

The absence of patterns of comparison did not permit a complete evaluation of the budget spending in 2000. The same set of items was never evaluated together in the same Fiscal Year. However, the inventory managers have felt more comfortable to make their budget spending decisions.

III. THE ALTERNATIVE MODELS

By trying to improve the inventory control model currently used by the Brazilian Navy, we will use the underlying principles of the so-called system approach developed by Craig C. Sherbrooke in the book *Optimal Inventory Modeling of Systems- Multi Echelon Techniques* and published in 1992. [Ref. 6]

Additionally, we will manipulate the weights assigned to each parameter of the MEG algorithm in order to find a better set of weights since the current weights were assigned based on intuition rather than formal methods. This manipulation should create a more robust SPAADA, which will be called modified SPAADA. The latter will be also compared to our adaptations of Sherbrooke's model.

A. THE FIRST ALTERNATIVE – STOCKING BY MARGINAL ANALYSIS (SBMA)

We developed the Stocking by Marginal Analysis (SBMA) model based on underlying principles of the system approach, as discussed by Sherbrooke in *Optimal Inventory Modeling of Systems*. [Ref. 6]. Sherbrooke's method minimizes the expected number of backorders in a system of repairable items by using system availability or total investment as inputs. Smith et al. (1972) show that minimizing backorders is equivalent to maximizing availability. The reason for limiting the model for repairable items was based only on the fact that they comprise the availability of weapon systems and the largest part of the budget. [Ref. 6:p.20]

The assumptions of Sherbrooke's model are:

- For a stock level *s*, a reorder or repair of one unit is initiated whenever the level falls to (*s* – 1),
- The failure of a single item makes the end item unavailable, and
- There are no cannibalizations.

Sherbrooke's model also assumes that demand for spare parts follows the Poisson distribution, which is based on the following variables:

$$P(x) = \frac{(mT)^x \; e^{-mT}}{x!}$$

where

P (x) is the probability density function,

m is the average annual demand, and

T is the average time period (lead time).

The stock level s = OH + DI – BO, where OH represents the units of stock on hand, DI the units due in and BO the number of backorders.

The Expected Number of Backorders is calculated as follows:

$$EBO(s) = \Pr\{DI = s + 1\} + 2\Pr\{DI = s + 2\} + 3\Pr\{DI = s + 3\} + ...$$

$$= \sum_{x = s+1}^{\infty} (x - s) \Pr\{DI = x\},$$

where

DI is the number of units of stock due-in from repair or re-supply,

S is the stock level, and

Pr{DI} is the steady-state probability for the number of units due-in, when the units in stock are continually incremented.

To find the optimal availability-cost curve Sherbrooke uses technique called Marginal Analysis, where each step in the algorithm observes its influence on each item to determine whether the next item should be bought [Ref. 6:p. 28].

The following algorithm permits the calculation of the marginal value, also called the *delta value* (Δ), which represents the increase in the system effectiveness per monetary units, obtained when an additional unit of that item is stocked:

$$\Delta = \frac{EBO_i(s) - EBO_i(s + 1)}{\mathbf{C}_i}$$

where

Δ	is the delta value,
$EBO_i(s)$	is the expected number of backorders for item i at stock level *s*, and
C_i	is the cost of an item i.

The delta value calculations were performed for each item based on the increment of units in stock until some point when this process does not provide any increase in the system effectiveness, thus meaning a delta value is negligible. The marginal analysis technique adds one unit of that item having the highest Δ value to the spares mix successively, until the budget is exhausted.

1. Our Model

Our problem differs from that addressed by Sherbrooke in the following ways:

- The set of 3000 items are not spare parts of one single end-item,
- These items are not considered repairables, since repairs are performed outside the Brazilian Navy supply system. It is thus possible to assume that the probability of repair is always zero since all the items were reordered and the repair/order time was equivalent to the lead time,
- The orders are not placed every time the inventory levels fall to ($s - 1$).

Nevertheless, the problem is similar because:

- The Brazilian Navy can be considered a system of sorts,
- Both have a fixed budget as input, which is defined for a particular period of time, usually a year, and
- The stockout (shortage) conditions do not result in a lost sale, where the demand for the item is lost and not filled, but in a backorder, where the fill is delayed in delivery.

The following assumptions were necessary to make this adaptation:

- The expected demand for the sample items follows a Poisson distribution. Poisson is generally considered a good model when mean demand is low. We did not have sufficient data to verify this assumption.
- The average time period or replenishment lead time (T) is equal to 0.5 for any item in our model.

The reason for assuming T = 0.5 because replenishment only occurs once per year and the times of a Poisson process in a time interval are distributed uniformly. For example, consider a particular item that is demanded 8 different times during a one-year period according to the following chart:

(JAN/1st/Y1) A B C D E F G H (JAN/1st/Y2)

Each letter corresponds to one unit demanded for this item. The lead time for each demanded item is presented in Table 6.

UNIT	**LEAD TIME (in years)**
A	8/9
B	7/9
C	6/9
D	5/9
E	4/9
F	3/9
G	2/9
H	1/9

Table 5. Lead Time for One Particular Item During a One-Year Period.

The average lead time (T) for this item will be: T = (8/9 + 7/9 + 6/9 + 5/9 + 4/9 + 3/9 + 2/9 + 1/9) / 8 = 0.5 years.

2. Methodology

Using Microsoft Excel, we developed spreadsheets that calculate the Expected of Backorders (EBO) based on the Poisson distribution, and perform the marginal analysis. Additionally, we work with the same performance measures (service level and fill rate) currently used by the Brazilian Navy. The service level is the main focus of the analysis and the fill rate will be calculated in order to give the reader a broader analysis of the results.

Our methodology is based on the following steps:

- Perform the delta value calculations for each item,
- Calculate the Expected Number of Backorders (EBO) based on a different number of units in stock (s) and the delta value for each item,
- Rank the entire collection of delta values in descending order,
- Purchase items with a higher delta value until the limit imposed by the budget constraint is achieved, and
- Compare the total number of purchased items with its actual demand to permit the calculation of the service levels that could be used as a comparison measurement for the SPAADA model.

Appendix B present a detailed description of the spreadsheets used to develop SBMA model.

B. THE SECOND ALTERNATIVE – MODIFIED SPAADA

The weights in the SPAADA model were one of the major concerns because they were not based on any technical methodology. We address this weakness by using a genetic algorithm to establish a better set of weights.

Genetic algorithms mimic Darwinian principles of natural selection by creating an environment where hundreds of possible solutions to a problem can compete with one another and only the "fittest" survive. Just as in biological evolution, each solution can pass along its good "genes" through "offspring" solutions so that the entire population of solutions will continue to evolve better solutions. [Ref. 7:p. 23] We implement our model, called modified SPAADA, using genetic algorithms with a software package called Evolver, which is an add-in to Microsoft Excel.

In the modified SPAADA model, the genetic algorithm searches for the right combination of weights assigned to the parameters of the MEG algorithm based on a predefined objective function of minimizing the total number of backorders and, consequently, maximizing the service levels resulting from the difference between the forecasted and actual demand based on limitations imposed by budgetary constraints.

Because genetic algorithms do not guarantee optimal solutions, it is necessary to define a stopping rule for the search for a better set of weights in the MEG algorithm. We are aware that the terms optimal and best are not precise for this situation but will use them in the absence of better terminology. Also to reduce the search times, we limited the possible choices of weights to integer values between 1-10.

We develop the new model as follows:

- Calculate the MEG of each item using the original weights,
- Rank all items based on a MEG descending order,
- Calculate the total price of each item (unit price x forecast demand),
- Define the budget as 65% of the total cost of the sample of 3,000 items,
- From the highest to the lowest MEG, compute the accumulated total cost of the items, and
- Calculate the service level achieved when spending the budget to purchase the items until the limit imposed by the budget is reached.

Utilizing the genetic algorithms to achieve the objective function of minimizing the total number of backorders:

- Recalculate the MEG algorithm for each item based on variations in the weights assigned to each of its parameters,
- Re-rank all the items based on the same criteria (MEG descending order), and
- Based on the same budget constraint, calculate the new service level for the years 1998, 1999 and 2000.

When performing the simulation of the model we notice that, on average, after 2000 trials, no major improvements occurred in terms of minimizing the total number of backorders when the genetic algorithms attempt to improve the objective function.

Appendix B presents a detailed description of the spreadsheet used to develop the modified SPAADA model.

C. DATA

We received a sample of 3,000 items used in 2000 and indexed by NEB – the Brazilian Stock Number, from CCIM. The data includes for each item: unit price, the seven SPAADA parameters, actual demand for the years 1998, 1999 and 2000 and the forecast demand for the year 2001.

Because we did not have forecast values for years 1998, 1999 and 2000, we estimated those forecasts by calculate them "backwards", as follows:

<u>Forecast for 2000</u>

$F_{t+1} = \alpha A_t + (1 - \alpha) F_t$

$F_{2001} = \alpha A_{2000} + (1 - \alpha) F_{2000}$

$F_{2000} = (F_{2001} - \alpha A_{2000}) / (1-\alpha)$

<u>Forecast for 1999</u>

$F_{2000} = \alpha A_{1999} + (1 - \alpha) F_{1999}$

$F_{1999} = (F_{2000} - \alpha A_{1999}) / (1- \alpha)$

<u>Forecast for 1998</u>

$F_{1999} = \alpha A_{1998} + (1 - \alpha) F_{1998}$

$F_{1998} = (F_{1999} - \alpha A_{1998}) / (1 - \alpha)$

where

F_{xxxx} is the forecast demand for year xxxx,

A_{xxxx} is the actual demand for year xxxx, and

α is the exponential smoothing constant, assumed 0.5.

Regardless of the year, the budget used for each year was equivalent to 65% of the accumulated total cost of the 3,000 items (unit price x forecasted demand) for both alternatives. This is the same criterion the Brazilian Navy used for establishing the budget requirements when implementing SPAADA in 2000.

The authorized budget for the years 1998, 1999 and 2000 is shown in Table 5.

YEAR	**REAIS (R$)**	**U.S. DOLLARS (US$)**[1]
1998	R$ 11,173,832	US$ 4,138,456
1999	R$ 10,099,546	US$ 3,740,571
2000	R$ 9,183,345	US$ 3,401,239

Table 6. The Budget for 1998, 1999 and 2000.

[1] Exchange Rate: $ 1,00 equals to R$ 2.70, on August 30th, 2001.

IV. RESULTS

We compare our three models (SPAADA, SBMA and Modified SPAADA) with data from 1998 to 2000 with the two different scenarios of carrying over stocks from one year to the next and not carrying over stocks.

For each model and year we performed the following test:

- Calculate initial spare parts to purchase based on forecast demand and safety level for SPAADA and on the Poisson distribution and Marginal Analysis for SBMA,
- Spend the authorized budget, and
- Compare actual demand with the items purchased to calculate service levels and fill rates.

A. RESULTS OF NOT CARRYING OVER STOCKS

The achieved results when stocks were not carried over from one year to the next are shown in Tables 9, 10 and 11 and Figures 1, 2 and 3.

	NUMBER OF BACKORDERS (BO)		
YEAR	SPAADA	SBMA	MODIFIED SPAADA
1998	1079	422	959
1999	1106	342	953
2000	1296	319	1045

Table 7. Comparison of Number of Backorders for the Three Models.

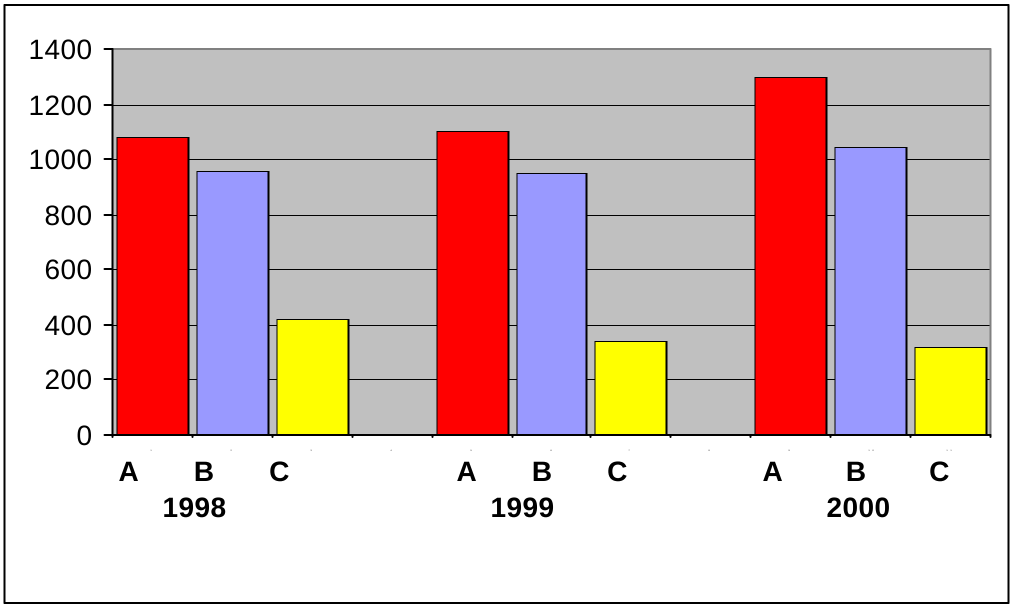

Figure 1. Histogram for Number of Backorders for SPAADA (A), Modified SPAADA (B) and SBMA (C).

	SERVICE LEVEL (1 – BO/3000)		
YEAR	SPAADA	SBMA	MODIFIED SPAADA
1998	64.03%	85.93%	68.03%
1999	63.13%	88.60%	68.23%
2000	56.80%	89.37%	65.17%

Table 8. Comparison of Service Levels for the Three Models.

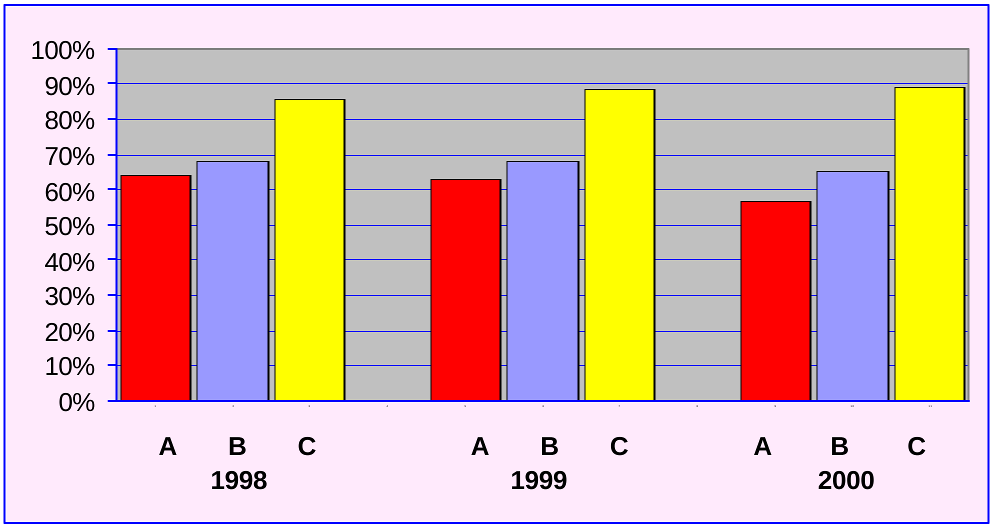

Figure 2. Histogram for Service Level SPAADA (A), Modified SPAADA (B) and BMA (C).

	FILL RATE		
YEAR	SPAADA	SBMA	MODIFIED SPAADA
1998	54.85%	81.73%	59.85%
1999	53.20%	86.04%	60.23%
2000	53.72%	88.75%	62.18%

Table 9. Comparisons of Fill Rates for the Three Models.

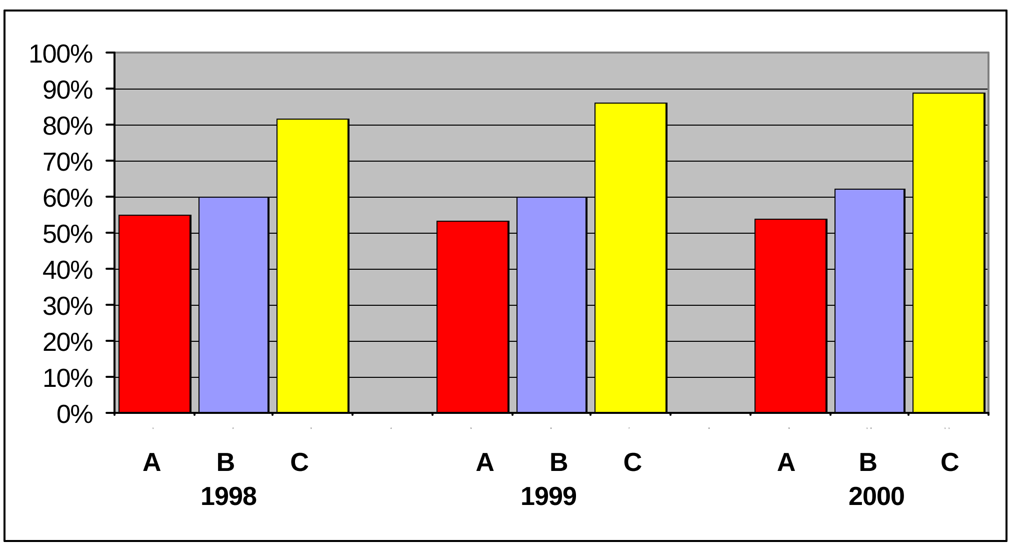

Figure 3. Histogram for Fill Rate for SPAADA (A), Modified SPAADA (B) and SBMA (C).

We can see that the results achieved by SBMA were consistently better than those provided by both versions of SPAADA. Additionally, the modified SPAADA, using weights suggested by the genetic algorithms, provided slightly better results than the original one.

When we tried to modify SPAADA, we also observed that the weights for the "optimal" solutions changed for the years 1998 to 1999, but were exactly the same for the years 1999 to 2000. The weights suggested by the genetic algorithms and the original are shown in Table 12.

PARAMETERS	SPAADA	1998	1999	2000
Demand's Frequency	3	2	2	2
Demand's Popularity	2	2	1	1
Demand's Regularity	3	6	10	10
Navy's Popularity	1	3	4	4
Criticality	2	2	3	3
Planned Program Requirements	1	1	1	1
Navy's Priority	2	3	5	5

Table 10. Weights Defined in SPAADA and Suggested by the Genetic Algorithm when Stocks are not Carried over to the Next Year.

We also observed in the SPAADA model that when using the optimal weights from 1998 in 1999 and from 1999 in 2000, the service level and fill rate for those years showed some improvement compared to the original version of SPAADA. The new service levels were 66.60 % and 63.32 % respectively. The new fill rates were 58.84 % and 60.73 %. This observation is important because the improved weights for any given year are not known before the year is over.

B. RESULTS WHEN CARRYING ON STOCK

When the models carried over stock from one year to the next, we assumed that the beginning inventory for 1998 was zero for all items. The end inventories for 1998 and 1999 are the beginning inventories for 1999 and 2000, respectively.

The achieved results when stock was carried on from one year to the next are shown in Tables 13, 14 and 15 and Figures 4, 5 and 6.

	NUMBER OF BACKORDERS (BO)		
YEAR	SPAADA	SBMA	MODIFIED SPAADA
1998	1079	422	959
1999	825	218	685
2000	888	150	670

Table 11. Comparison of Number of Backorders for the Three Models.

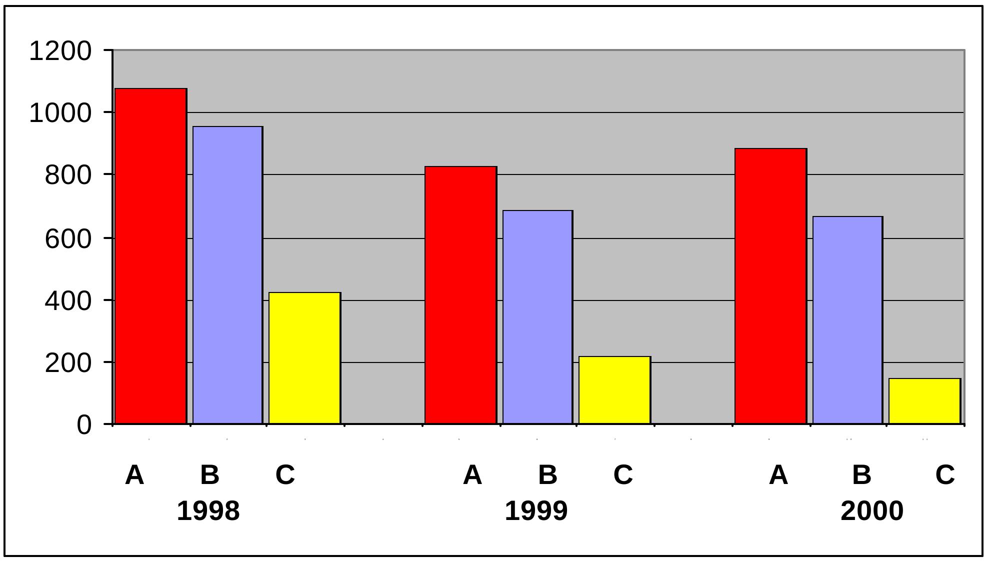

Figure 4. Histogram for Number of Backorders for SPAADA (A), Modified SPAADA (B) and SBMA (C).

	SERVICE LEVEL (1 – BO/3000)		
YEAR	SPAADA	SBMA	MODIFIED SPAADA
1998	64.03%	85.93%	68.03%
1999	72.50%	92.73%	77.17 %
2000	70.37%	95.00%	77.67%

Table 12. Comparison of Service Levels for the Three Models.

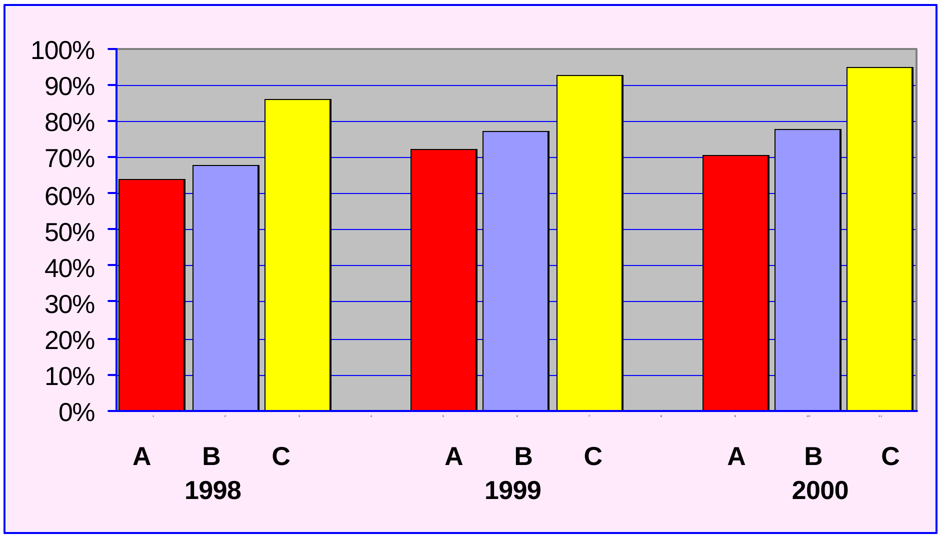

Figure 5. Histogram for Service Level for SPAADA (A), Modified SPAADA (B) and SBMA (C).

	FILL RATE		
YEAR	SPAADA	SBMA	MODIFIED SPAADA
1998	54.85%	81.73%	59.85%
1999	64.34%	90.39%	71.02%
2000	67.38%	94.89%	75.06%

Table 13. Comparisons of Fill Rates for the Three Models.

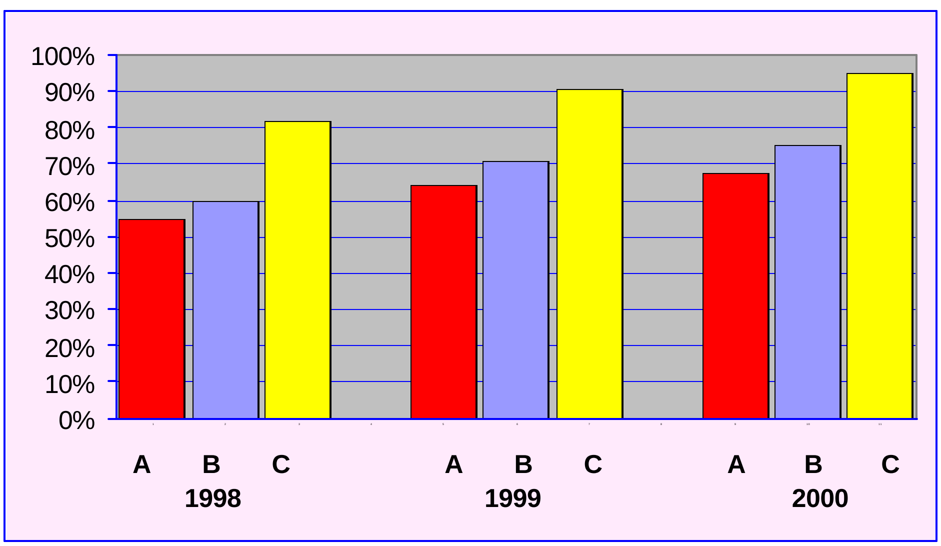

Figure 6. Histogram for Fill Rate for SPAADA (A), Modified SPAADA (B) and SBMA (C).

The new weights that were assigned for each parameter by the genetic algorithm when considering stock that was carried over from one year to the next are shown in Table 16.

PARAMETERS	SPAADA	1998	1999	2000
Demand Frequency	3	2	7	6
Demand Popularity	2	2	1	1
Demand Regularity	3	6	5	5
Navy Popularity	1	3	10	10
Criticality	2	2	1	1
Planned Program Requirements	1	1	5	5
Navy Priority	2	3	3	1

Table 14. Weights Defined in SPAADA and Suggested by the Genetic Algorithm when Stocks are Carried over from One Year to the Next.

This occurrence could not be run for more than three years to verify if these weights were converging on a specific set as happened when stock was not considered. In any case, when using the "optimal" weights found for 1999 in 2000, the service level and the fill rate improved when compared to SPAADA. The service level was 76.67% and the fill rate was 73.77%.

We can see that the results achieved by SBMA were even better than those provided by both versions of SPAADA when carrying over stocks.

C. RESULTS IN TERMS OF SPAADA PARAMETERS

Another important measure of comparison among SBMA, SPAADA and its modified version is related to the results of those approaches within each type of parameter.

Tables 17 and 18 show the number of times each model achieved better results, or the smallest number of backorders in the grades assigned to each parameter.

YEARS	SPAADA	SBMA	Modified SPAADA
1998	5	23	6
1999	4	26	4
2000	3	25	3

Table 15. Performance of Each Model When Stocks Are Not Carried Over.

YEARS	SPAADA	SBMA	Modified SPAADA
1999	1	30	1
2000	1	30	0

Table 16. Performance of Each Model When Stocks Are Carried Over.

Once more the results achieved by SBMA were consistently better than those achieved by SPAADA and its modified version.

When stocks were not carried over, we noticed that:

- Demand Frequency – In 1998, the modified SPAADA had the best indices(service level) for grades 9 and 7, but were not substantially higher than SBMA. In 2000, SPAADA had the best result in grade 7. In 1999, SBMA had the best results in all grades.
- Demand Popularity – In 1999 and 2000, SBMA achieved the most relevant results, but the modified version of SPAADA had almost the same indices. In 1998, the modified version of SPAADA performed better in grades 9 and 6 although its results in grades 2 and 1 were relatively poor for all three years.
- Demand Regularity – the modified version of SPAADA was somewhat better in grades 9 and 5 for all years, but SBMA was significantly better in grades 2 and 1 for any year
- Navy Popularity – SBMA is the best choice in this parameter. It had the best indices in practically all observations except where it had almost the same service level achieved by the modified version of SPAADA.
- Criticality of the item – This is the most important parameter of SPAADA regarding readiness. As SBMA considered all items as having the same criticality, it was expected that the modified versions of SPAADA would have the best results in this parameter. This was not the case. Actually, the modified version of SPAADA only had better results in 1999 and 2000 in

grade 9, which was the highest grade for this parameter, and the most relevant for readiness, but not very far removed from SBMA.

- Planned Program Requirements – SBMA performed better for all three years
- Navy Priority – SBMA performed better for all three years

When stocks were carried over, we noticed that SBMA achieved the best results for all the grades assigned to the parameters. Appendices C and D present a more detailed description of these results.

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V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

In the beginning of this thesis we discussed the complexity of the Brazilian Navy supply system, and how extremely diverse profiles, and the distance from the major supply sources and obsolescence, both of which increase lead times, are hurdles that are very difficult to overcome. We had shown also that another factor that influences the performance of the supply system is the absence of an adequate inventory management process. This is absolutely necessary in a time of budget constraints.

Afterwards, we described SPAADA, a new model developed by the Brazilian Navy, in an attempt to improve the current inventory management process.

In the attempt to provide an alternative model to increase the efficiency of the Brazilian Navy supply system, we presented two alternatives to SPAADA. The first one, called Stocking by Marginal Analysis (SBMA), was developed using the underlying principles of Sherbrooke's model. The second one used the concept of genetic algorithms to improve the weights assigned to the SPAADA parameters.

Finally, we presented the results of modeling the original SPAADA and its alternatives.

B. CONCLUSION

We are able to make the following conclusions based on the analysis of the results achieved after modeling the current version of SPAADA, the modified version of SPAADA and the SBMA model:

- The SBMA model presented results that are far superior to the other models. We believe that SBMA achieved better results in terms of service levels because its marginal analysis concept is directly related to the unit price of each item. Thus, it prioritizes the budget spending on items that, even when providing the same contribution in terms of minimizing the expected number of backorders, have lower prices. It was then possible to purchase a larger number of items and thereby minimize the number of backorders and increase service levels. On the other hand, SPAADA has a tendency to prioritize items that have higher grades in different parameters.

- The modified SPAADA model presented slightly better results than the original SPAADA model. This occurred because the genetic algorithms provided parameters with better weights than those established in the original version, thus making it possible to achieve better results in the number of backorders and service levels.
- Both the original version of SPAADA and its modified version presented better results for highly critical items because the concept behind SPAADA gives budget spending priority to items with higher grades.
- The SBMA model is especially strong when stock is carried forward in a model that is designed to obtain the higher benefit from each dollar spent because more money must be spent in the following years, and therefore even better service levels are achieved.

C. RECOMMENDATIONS

We recommend that:

- The SPAADA weights be changed immediately using those suggested by the genetic algorithm in the previous year,
- The Brazilian Navy ICP – CCIM – take immediate action to develop software to implement a SBMA-like model,
- CCIM conduct further testing – possibly by using SBMA alongside SPAADA for one year before making a full transition, and
- The Brazilian Navy should continue its efforts to increase the number of items with reliable attributes, such as historical demand and unit price.

APPENDIX A. THE MICROSOFT EXCEL SPREADSHEET USED FOR SBMA

The concept of marginal analysis considers that at each step in the algorithm it is only necessary to look at one number for each item to determine the next item that should be purchased.

This approach requires the step-by-step calculation of the marginal or incremental increase in the system, called delta value, until some point where this increase can be ignored.

Microsoft Excel was not considered an ideal tool to perform these calculations because it did not provide an automated way to define when the delta values could be ignored nor does it re-rank these values in a descending order every time one item is purchased. Some manual interventions and combinations of spreadsheets were necessary to accomplish these tasks.

It was decided that the point where the increase in the delta value could be considered no longer relevant should be based on the forecast demand for each item. The original sample of 3,000 items was divided into three sets of forecast demand values. The total number of Δ value calculations is shown in Table 7.

Forecast Demand	**Total Number of D Value Calculations**
FD < = 10	15
10 < FD < = 25	30
FD > 25	150

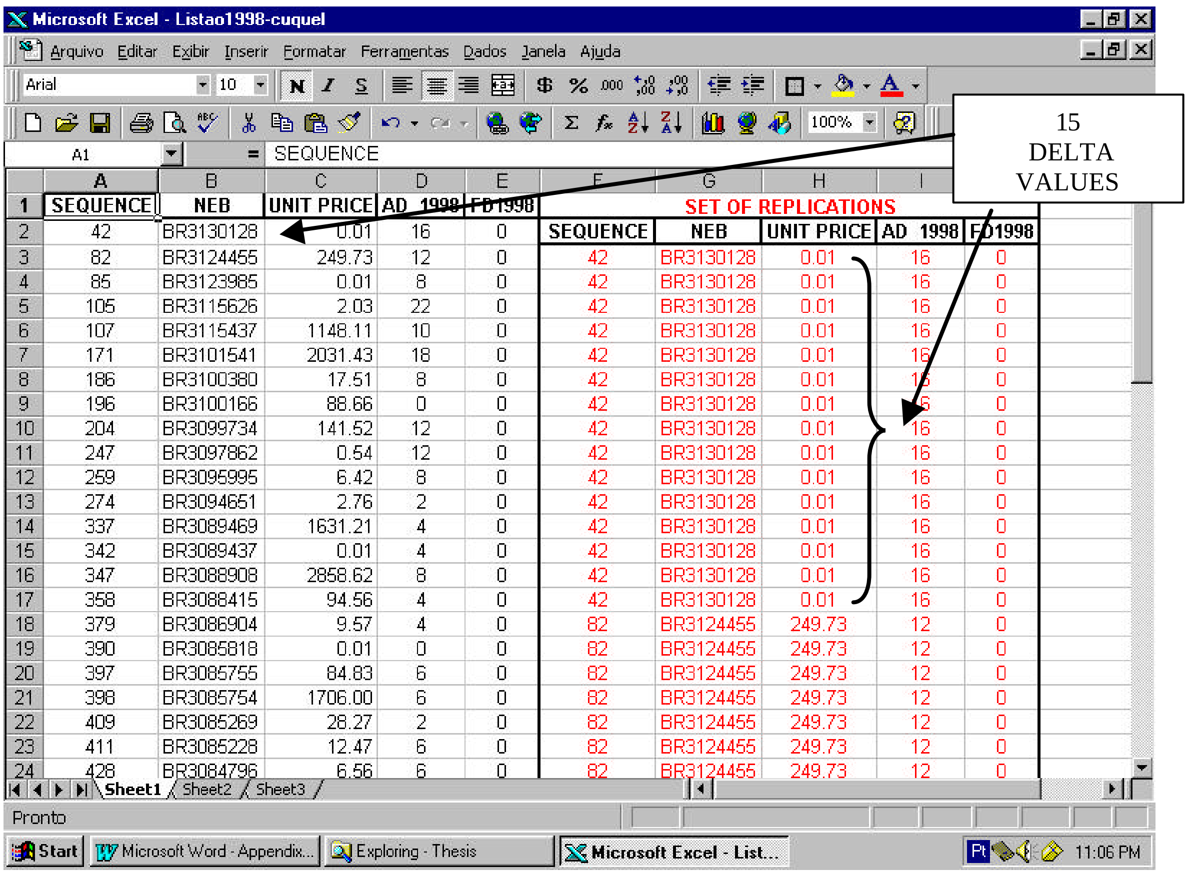
Table 17. Distribution of Δ Value Calculations per Each Range of Forecast Demand.

These Δ value calculations created a secondary spreadsheet of 65,415 registers composed of:

- Column A — item's sequence, based on the ascending forecast demand order,
- Column B — NEB,

- Column C unit price,
- Column D actual demand (AD),
- Column E forecast demand (FD), and
- Columns F to J delta value of each item, based on the Table 7.

Figure 1 presents the 15 Δ value calculations for the item BR3130128 with the smallest forecasted demand (zero).



	A	B	C	D	E	F	G	H	I	J
1	SEQUENCE	NEB	UNIT PRICE	AD 1998	FD1998	SET OF REPLICATIONS				
2	42	BR3130128	0.01	16	0	SEQUENCE	NEB	UNIT PRICE	AD 1998	FD1998
3	82	BR3124455	249.73	12	0	42	BR3130128	0.01	16	0
4	85	BR3123985	0.01	8	0	42	BR3130128	0.01	16	0
5	105	BR3115626	2.03	22	0	42	BR3130128	0.01	16	0
6	107	BR3115437	1148.11	10	0	42	BR3130128	0.01	16	0
7	171	BR3101541	2031.43	18	0	42	BR3130128	0.01	16	0
8	186	BR3100380	17.51	8	0	42	BR3130128	0.01	16	0
9	196	BR3100166	88.66	0	0	42	BR3130128	0.01	16	0
10	204	BR3099734	141.52	12	0	42	BR3130128	0.01	16	0
11	247	BR3097862	0.54	12	0	42	BR3130128	0.01	16	0
12	259	BR3095995	6.42	8	0	42	BR3130128	0.01	16	0
13	274	BR3094651	2.76	2	0	42	BR3130128	0.01	16	0
14	337	BR3089469	1631.21	4	0	42	BR3130128	0.01	16	0
15	342	BR3089437	0.01	4	0	42	BR3130128	0.01	16	0
16	347	BR3088908	2858.62	8	0	42	BR3130128	0.01	16	0
17	358	BR3088415	94.56	4	0	42	BR3130128	0.01	16	0
18	379	BR3086904	9.57	4	0	82	BR3124455	249.73	12	0
19	390	BR3085818	0.01	0	0	82	BR3124455	249.73	12	0
20	397	BR3085755	84.83	6	0	82	BR3124455	249.73	12	0
21	398	BR3085754	1706.00	6	0	82	BR3124455	249.73	12	0
22	409	BR3085269	28.27	2	0	82	BR3124455	249.73	12	0
23	411	BR3085228	12.47	6	0	82	BR3124455	249.73	12	0
24	428	BR3084796	6.56	6	0	82	BR3124455	249.73	12	0

Figure 7. Delta Value Calculations of Item BR3120128.

It was not possible to use only one spreadsheet because of the size of this file and the complexity of the involved calculations, especially the Poisson and delta values. It was necessary to divide it into nine smaller spreadsheets.

It took about two hours to do these calculations for each year – 1998, 1999 and 2000 on a 1.2 GHz PC computer with 128 Mb of RAM.

The distribution of the sample in the nine spreadsheets is shown in Table 18.

SPREADSHEET	RANGE	DELTA VALUE CALCULATIONS	TOTAL NUMBER OF DELTA VALUES CALCULATIONS
1ST	1 to 500	15	7500
2ND	501 to 1000	15	7500
3RD	1001 to 1501	15	7500
4TH	1501 to 2000	15	7500
5TH	2001 to 2503	15	7545
6TH	2504 to 2692	30	5670
7TH	2693 to 2892	30	6000
8TH	2893 to 2946	150	8100
9TH	2947 to 3000	150	8100

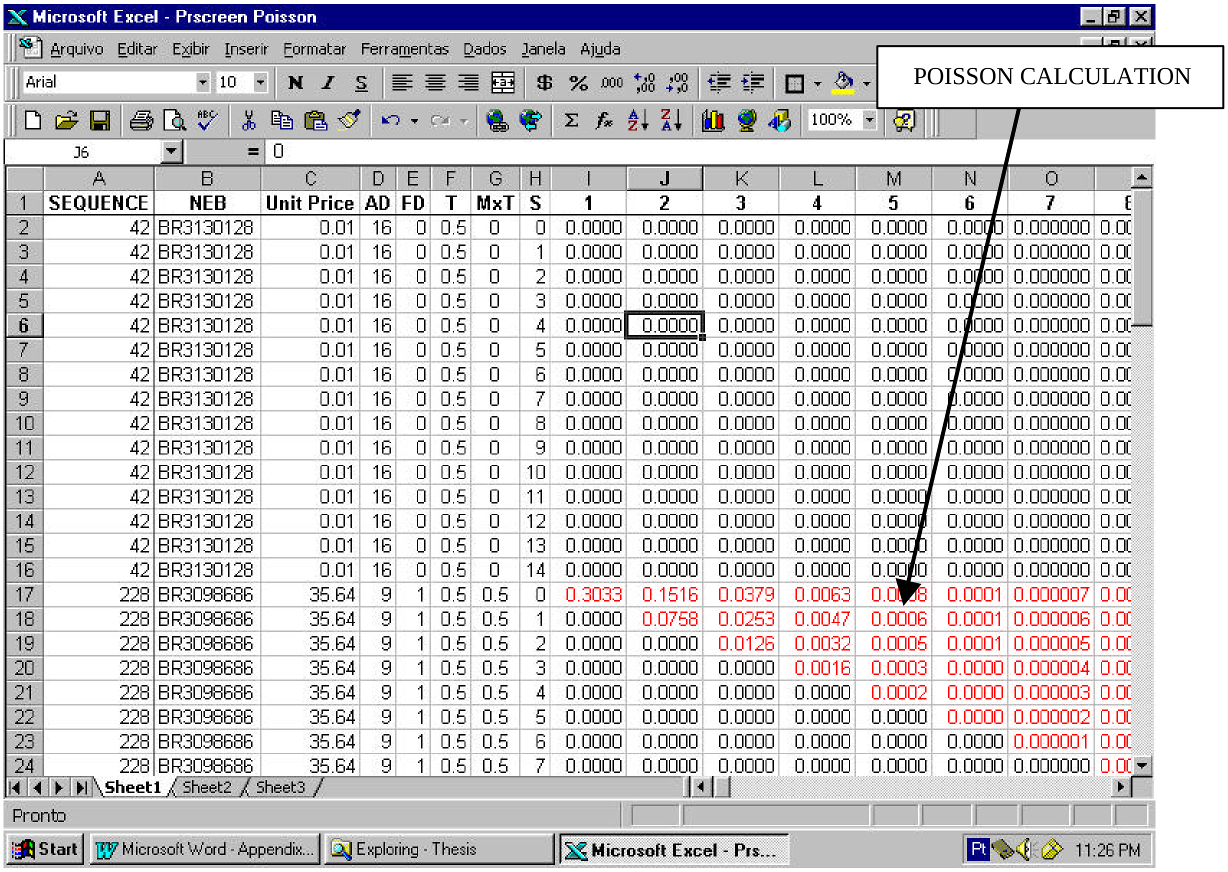
Table 18. Distribution of the Sample into the Nine Spreadsheets.

Each one of these nine spreadsheets performed the marginal analysis calculations of the delta value based on the increase of the effectiveness of the system resulting from the reduction in the number of expected backorders when incrementing the stock. The Poisson distribution was also used.

The spreadsheets were created as follows:

- Column A — Item's sequence, based on the ascending forecast demand order,
- Column B — NEB,
- Column C — unit price,
- Column D — actual demand (AD),
- Column E — forecast demand (FD or M),
- Column F — lead time (T),
- Column G — pipeline (M x T),
- Column H — total number of units in stock (s),
- Columns I to FB — incremental number of units due-in,
- Column FC — expected number of backorders (EBO), and
- Column FD — delta value (Δ)

Figures 2 and 3 present the structure of the spreadsheets designed to calculate the Poisson and the delta values.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1	SEQUENCE	NEB	Unit Price	AD	FD	T	MxT	S	1	2	3	4	5	6	7	8
2	42	BR3130128	0.01	16	0	0.5	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
3	42	BR3130128	0.01	16	0	0.5	0	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
4	42	BR3130128	0.01	16	0	0.5	0	2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
5	42	BR3130128	0.01	16	0	0.5	0	3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
6	42	BR3130128	0.01	16	0	0.5	0	4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
7	42	BR3130128	0.01	16	0	0.5	0	5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
8	42	BR3130128	0.01	16	0	0.5	0	6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
9	42	BR3130128	0.01	16	0	0.5	0	7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
10	42	BR3130128	0.01	16	0	0.5	0	8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
11	42	BR3130128	0.01	16	0	0.5	0	9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
12	42	BR3130128	0.01	16	0	0.5	0	10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
13	42	BR3130128	0.01	16	0	0.5	0	11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
14	42	BR3130128	0.01	16	0	0.5	0	12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
15	42	BR3130128	0.01	16	0	0.5	0	13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
16	42	BR3130128	0.01	16	0	0.5	0	14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0
17	228	BR3098686	35.64	9	1	0.5	0.5	0	0.3033	0.1516	0.0379	0.0063	0.0[illegible]8	0.0001	0.000007	0.0
18	228	BR3098686	35.64	9	1	0.5	0.5	1	0.0000	0.0758	0.0253	0.0047	0.0006	0.0001	0.000006	0.0
19	228	BR3098686	35.64	9	1	0.5	0.5	2	0.0000	0.0000	0.0126	0.0032	0.0005	0.0001	0.000005	0.0
20	228	BR3098686	35.64	9	1	0.5	0.5	3	0.0000	0.0000	0.0000	0.0016	0.0003	0.0000	0.000004	0.0
21	228	BR3098686	35.64	9	1	0.5	0.5	4	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.000003	0.0
22	228	BR3098686	35.64	9	1	0.5	0.5	5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000002	0.0
23	228	BR3098686	35.64	9	1	0.5	0.5	6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000001	0.0
24	228	BR3098686	35.64	9	1	0.5	0.5	7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000000	0.0

Figure 8. Structure of the Spreadsheets Designed to Calculate the Poisson Value.

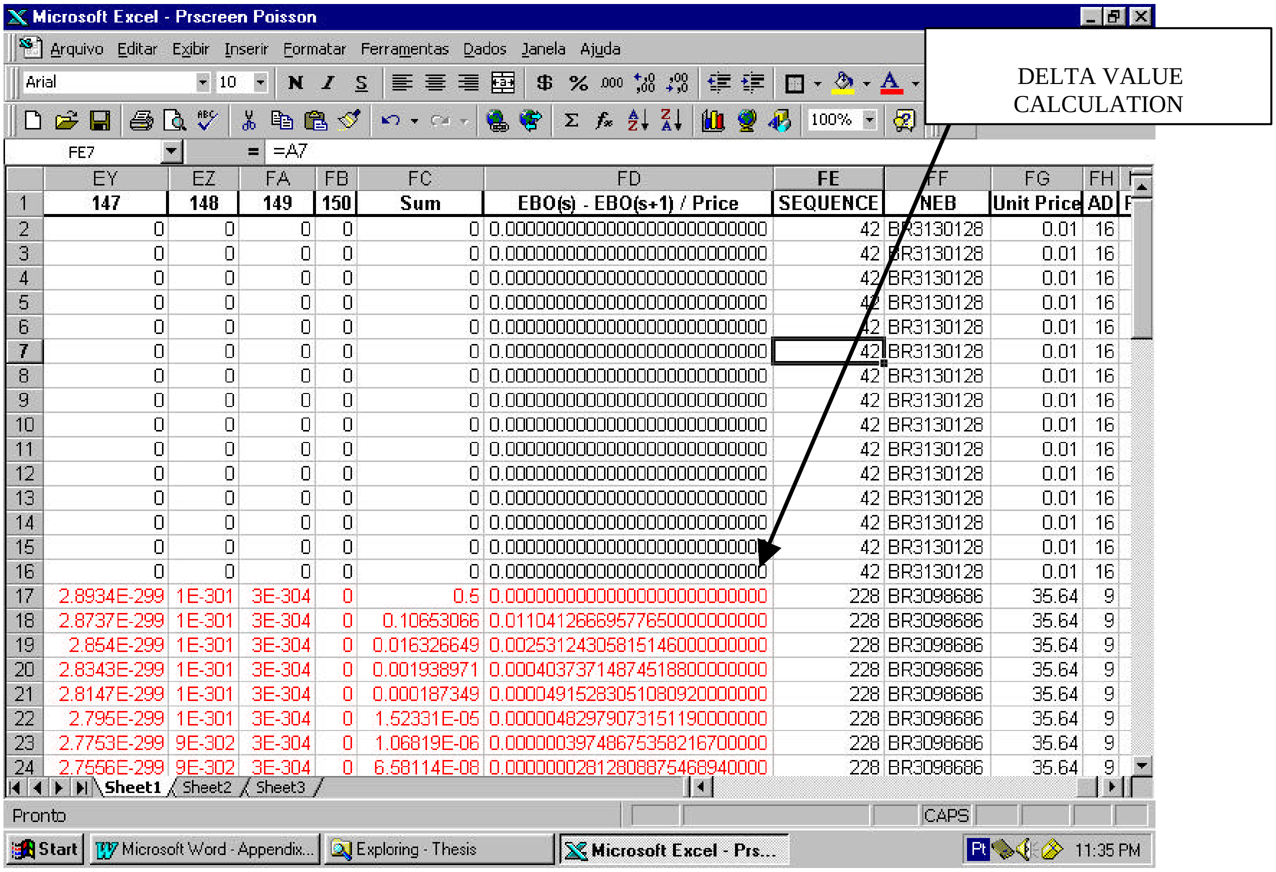


Figure 9. Structure of the Spreadsheets Designed to Calculate the Delta Value.

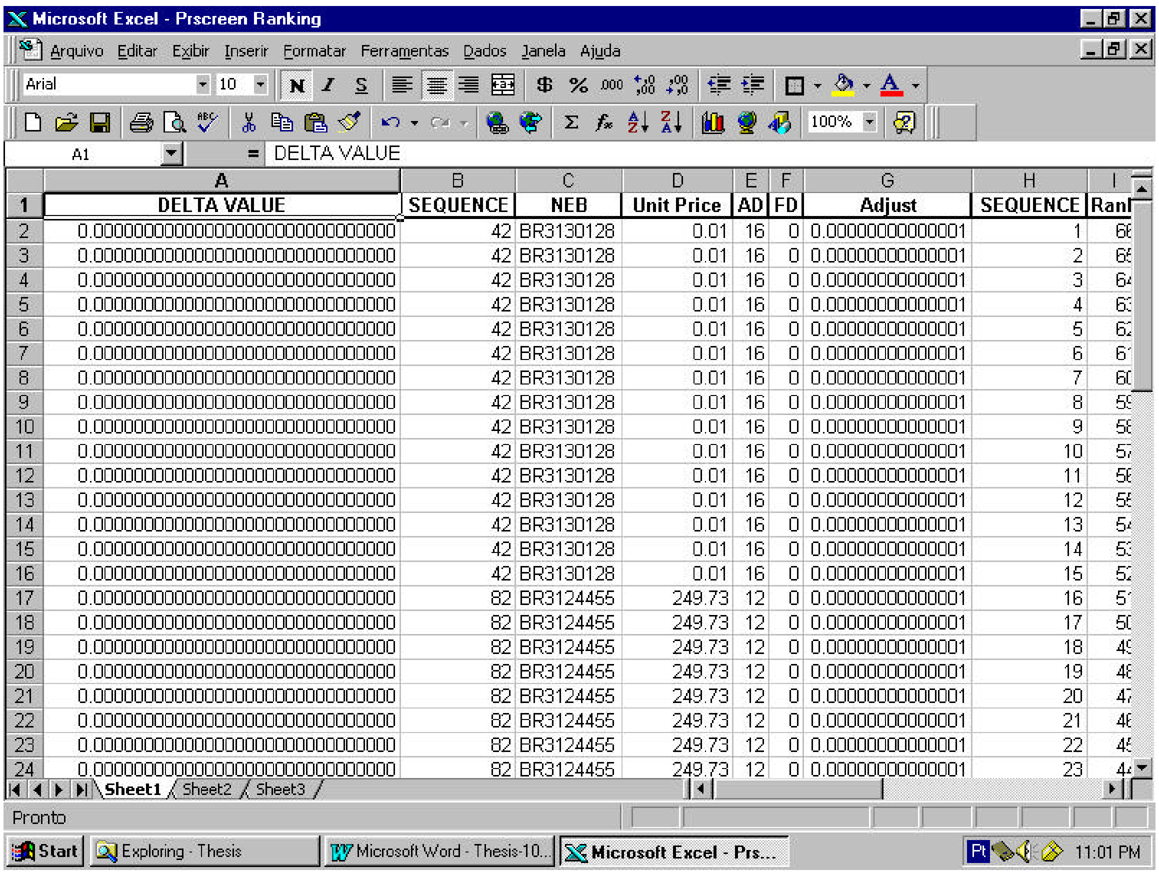
The next step was to rank the 65,415 delta values from the greatest to the smallest to permit to spend the budget with the items that provide greater system effectiveness per monetary unit.

The items that were divided in the nine spreadsheets were then consolidated into a single spreadsheet:

- Column A delta value,
- Column B item's sequence,
- Column C NEB,
- Column D unit price,
- Column E actual demand (AD),
- Column F forecast demand (FD),
- Columns G to M required for the use of VLOOKUP function of MS Excel,

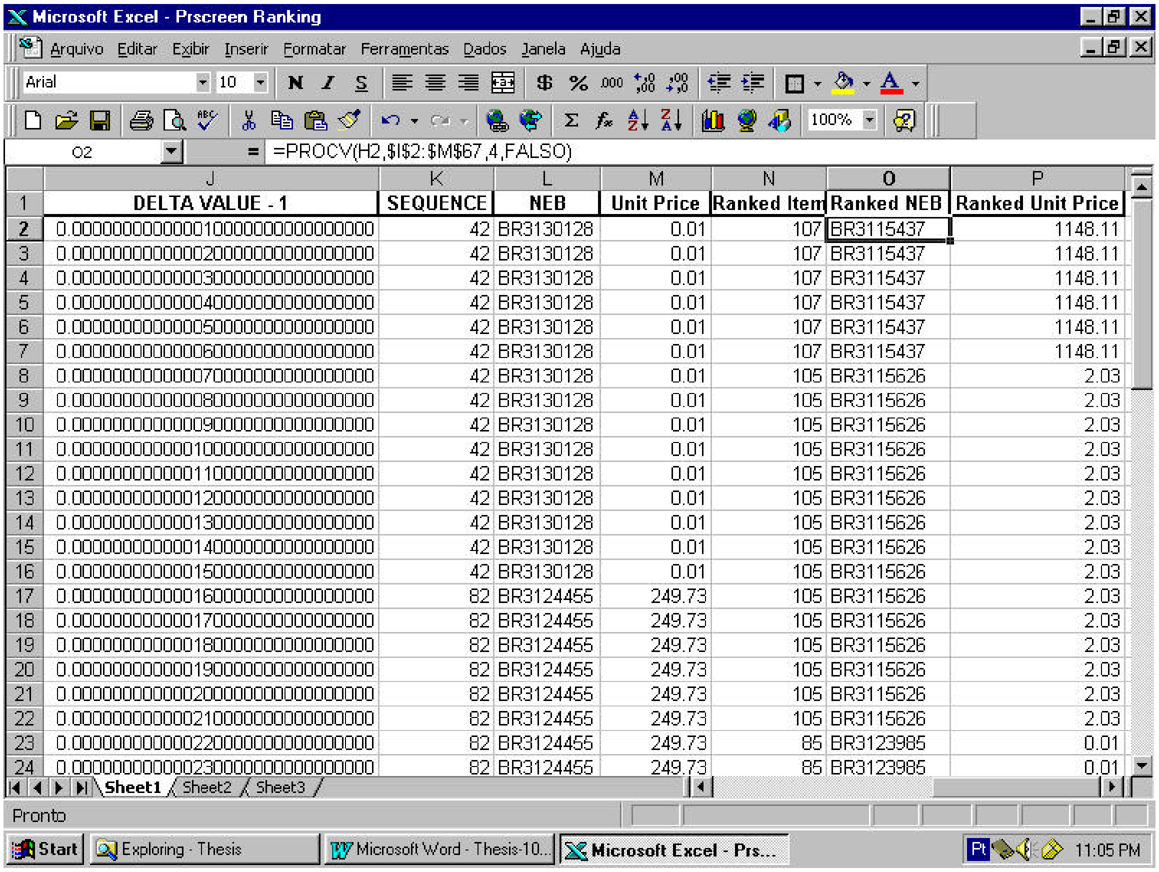
- Column N	ranked item based on its sequence,
- Column O	ranked NEB, and
- Column P	ranked unit price.

Figures 4 and 5 present the structure of the spreadsheet used to rank the delta values.



	A	B	C	D	E	F	G	H	I
1	DELTA VALUE	SEQUENCE	NEB	Unit Price	AD	FD	Adjust	SEQUENCE	Rank
2	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	1	68
3	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	2	65
4	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	3	64
5	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	4	63
6	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	5	62
7	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	6	61
8	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	7	60
9	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	8	59
10	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	9	58
11	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	10	57
12	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	11	56
13	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	12	55
14	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	13	54
15	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	14	53
16	0.0000000000000000000000000000000	42	BR3130128	0.01	16	0	0.00000000000001	15	52
17	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	16	51
18	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	17	50
19	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	18	49
20	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	19	48
21	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	20	47
22	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	21	46
23	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	22	45
24	0.0000000000000000000000000000000	82	BR3124455	249.73	12	0	0.00000000000001	23	44

Figure 10.	Structure of the Spreadsheet used to Rank the Delta Values.



Microsoft Excel - Prscreen Ranking

O2 = =PROCV(H2,$I$2:$M$67,4,FALSO)

	J	K	L	M	N	O	P
1	DELTA VALUE - 1	SEQUENCE	NEB	Unit Price	Ranked Item	Ranked NEB	Ranked Unit Price
2	0.00000000000000100000000000000000	42	BR3130128	0.01	107	BR3115437	1148.11
3	0.00000000000000200000000000000000	42	BR3130128	0.01	107	BR3115437	1148.11
4	0.00000000000000300000000000000000	42	BR3130128	0.01	107	BR3115437	1148.11
5	0.00000000000000400000000000000000	42	BR3130128	0.01	107	BR3115437	1148.11
6	0.00000000000000500000000000000000	42	BR3130128	0.01	107	BR3115437	1148.11
7	0.00000000000000600000000000000000	42	BR3130128	0.01	107	BR3115437	1148.11
8	0.00000000000000700000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
9	0.00000000000000800000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
10	0.00000000000000900000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
11	0.00000000000001000000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
12	0.00000000000001100000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
13	0.00000000000001200000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
14	0.00000000000001300000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
15	0.00000000000001400000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
16	0.00000000000001500000000000000000	42	BR3130128	0.01	105	BR3115626	2.03
17	0.00000000000001600000000000000000	82	BR3124455	249.73	105	BR3115626	2.03
18	0.00000000000001700000000000000000	82	BR3124455	249.73	105	BR3115626	2.03
19	0.00000000000001800000000000000000	82	BR3124455	249.73	105	BR3115626	2.03
20	0.00000000000001900000000000000000	82	BR3124455	249.73	105	BR3115626	2.03
21	0.00000000000002000000000000000000	82	BR3124455	249.73	105	BR3115626	2.03
22	0.00000000000002100000000000000000	82	BR3124455	249.73	105	BR3115626	2.03
23	0.00000000000002200000000000000000	82	BR3124455	249.73	85	BR3123985	0.01
24	0.00000000000002300000000000000000	82	BR3124455	249.73	85	BR3123985	0.01

Figure 11. Structure of the Spreadsheet used to Rank the Delta Values.

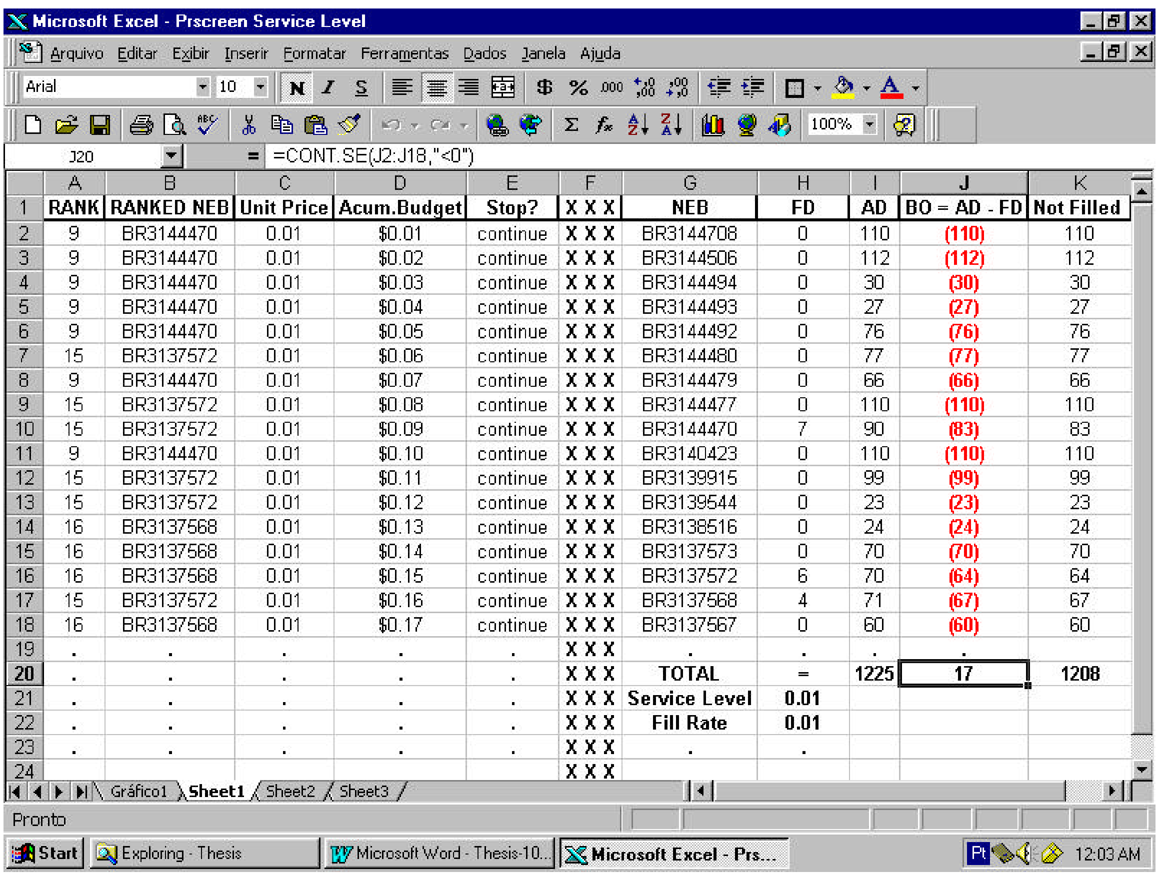
The next step of evaluating the applicability of the SBMA model required the use of another spreadsheet designed to spend the predetermined budget and calculate the service level and fill rate achieved by the model.

The spreadsheet was designed as follows:

- Column A — rank
- Column B — ranked NEB
- Column C — unit price
- Column D — accumulated budget
- Column E — stop? – defines when the accumulated budget achieves the limit of the available budget
- Column F — X X X
- Column G — NEB

- Column H forecast demand (FD)
- Column I actual demand (AD)
- Column J number of backorders (BO= AD – FD)
- Column K not filled (number of units not filled)
- Cell I20 total number of units actually demanded;
- Cell J20 total number of backorders
- Cell K20 total number of units not filled
- Cell H21 service level
- Cell H22 fill rate

Figure 6 presents the structure of the spreadsheet used to calculate the service level and fill rate based on rank and budget constraint.



	A	B	C	D	E	F	G	H	I	J	K
1	RANK	RANKED NEB	Unit Price	Acum.Budget	Stop?	X X X	NEB	FD	AD	BO = AD - FD	Not Filled
2	9	BR3144470	0.01	$0.01	continue	X X X	BR3144708	0	110	(110)	110
3	9	BR3144470	0.01	$0.02	continue	X X X	BR3144506	0	112	(112)	112
4	9	BR3144470	0.01	$0.03	continue	X X X	BR3144494	0	30	(30)	30
5	9	BR3144470	0.01	$0.04	continue	X X X	BR3144493	0	27	(27)	27
6	9	BR3144470	0.01	$0.05	continue	X X X	BR3144492	0	76	(76)	76
7	15	BR3137572	0.01	$0.06	continue	X X X	BR3144480	0	77	(77)	77
8	9	BR3144470	0.01	$0.07	continue	X X X	BR3144479	0	66	(66)	66
9	15	BR3137572	0.01	$0.08	continue	X X X	BR3144477	0	110	(110)	110
10	15	BR3137572	0.01	$0.09	continue	X X X	BR3144470	7	90	(83)	83
11	9	BR3144470	0.01	$0.10	continue	X X X	BR3140423	0	110	(110)	110
12	15	BR3137572	0.01	$0.11	continue	X X X	BR3139915	0	99	(99)	99
13	15	BR3137572	0.01	$0.12	continue	X X X	BR3139544	0	23	(23)	23
14	16	BR3137568	0.01	$0.13	continue	X X X	BR3138516	0	24	(24)	24
15	16	BR3137568	0.01	$0.14	continue	X X X	BR3137573	0	70	(70)	70
16	16	BR3137568	0.01	$0.15	continue	X X X	BR3137572	6	70	(64)	64
17	15	BR3137572	0.01	$0.16	continue	X X X	BR3137568	4	71	(67)	67
18	16	BR3137568	0.01	$0.17	continue	X X X	BR3137567	0	60	(60)	60
19	.	.	.	.	.	X X X	.	.	.	.	
20	.	.	.	.	.	X X X	TOTAL	=	1225	17	1208
21	.	.	.	.	.	X X X	Service Level	0.01			
22	.	.	.	.	.	X X X	Fill Rate	0.01			
23	.	.	.	.	.	X X X	.	.			
24						X X X					

Figure 12. Structure of the Spreadsheet used to Calculate the Service Level and Fill Rate.

APPENDIX B. THE MICROSOFT EXCEL SPREADSHEET USED WITH EVOLVER

In order describe the Microsoft Excel spreadsheets that would be used in conjunction with the genetic algorithms, it was decided to separate the sources of data into two different sets and point out the respective cells where the information is located in the spreadsheet:

- Data acquired from the Brazilian Navy-ICP
- Data from calculations performed on the spreadsheet

The data acquired from Brazil was composed of:

1. Inventory System and Decision Variables Parameters… cells B2 to H2
2. NEB.. cells A6 and Q6
3. Demand's frequency... cell B6
4. Demand's Popularity.. cell C6
5. Demand's regularity... cell D6
6. Navy's popularity... cell E6
7. Criticality... cell F6
8. Planned Program Requirements .... cell G6
9. Navy's priority.. cell H6
10. Unit Price.. cell R6
11. Forecast Demand + Safety Level .... cell S6
12. Actual Demand .... cell T6

The description of the spreadsheet used by Evolver is presented in Table 17.

DESCRIPTION	CELL	FORMULA
BUDGET	B3	=SUM(AB7:AB3006)* 0.65
The budget is equivalent to 65 % of the sum of unit prices of each item of the sample (3,000 items).		
SERVICE LEVEL	K1	= AE3009/3000
The service level is the probability that demand is satisfied immediately from on-hand inventory. The cell AE3009 represents the total number of items in backorder.		
MEG-1	I6	={[(3 x DF)+(2 x DP)+(3 x DR)+(1 x NP)+(3 x C)+(1 x PPR)+(2 x NPr)]/15}
The MEG-1 algorithm intends to calculate the relative importance of each item with respect to the rest of the data base based on the assigned weights to the parameters.		
UNTIE	J6	X X X
This cell has very low values (decimals) and they were added to cell I6 to eliminate equal values of MEG because the Microsoft Excel function designed to rank those items (VLOOKUP) does not permit the existence of equal values to be ranked.		
MEG-2	K6	= I7 + J7
The MEG-2 has almost the same value of MEG-1 and is different because of the low values added to untie it.		
MATCH	L6	= MATCH(K7,K8:K3006,0)
This cell was designed to verify if there was any coincidence in the final values of MEG.		
TRUE/FALSE	M6	= ISNUMBER(L7)
This cell was designed to check if there are any numbers that are equal to one another, restricting the rank of the items.		
SEQUENCE	N6	X X X
This cell presents the sequence of the items that will be based the ranking, from 1 to 3,000.		
RANK	O6	= RANK(P7,P$7:P$3006)
This cell provides the ranking of the data base, from 1 to 3,000.		
MEG-3	P6	= IF(M7=TRUE,K7 + 0.00000001,K7)
This cell intends, also, to eliminate any possible equality among the 3,000 MEG values.		
RANKED MEG	U6	= VLOOKUP (N7,O$7:P$3006,2,FALSE)
This cell Ranks the MEG from the higher to the lower values.		
NSN	V6	= VLOOKUP (N7,O$7:Q$3006,3,FALSE)
This cell presents the NSN associated to the calculated MEG, recovered from column Q.		
PRICE	W6	= VLOOKUP (N7,O$7:R$3006,4,FALSE)
This cell presents the Price associated to the calculated MEG, recovered from column R.		
ED + SL	X6	= VLOOKUP (N7,O$7:S$3006,5,FALSE)
This cell presents the Estimated Demand (ED) plus the Safety Level (SL) associated to the calculated MEG, recovered from column S.		
ACTUAL DEMAND	Y6	= VLOOKUP (N7,O$7:T$3006,6,FALSE)
This cell presents the Actual Demand associated to the calculated MEG, recovered from column T.		
PRICE x ESTIMATED DEMAND	Z6	= W7 x X7
This cell calculates the estimated total purchase cost of each ranked item.		
ACCUM PRICE	AA8	= Z8 + AA7
This cell calculates the total accumulated costs of the ranked items, from the higher to the lower MEG		
(ED + SL) – ACTUAL DEMAND	AB6	= IF(AA7<=$B$3,X7-Y7, -Y7)
This cell has two functions: limit the purchases by budget constraints and define the total number of items that, based on the estimations, will promote backorders. The budget constraints will be evaluated by the comparison between the budget (cell B3) and the total cost of the most important items, based on the rank. The total number of backorders will be defined by the positive or negative values assigned to the formula, whenever there was a surplus or deficit when comparing estimated demand and safety levels with actual demand.		
NUMBER OF BACKORDERS	AC6	= IF(AB7<0,1,0)
This cell calculates the total number of backorders, assigning the value "1" whenever there was an occurrence of backorders for each item.		
DEMANDED ITEMS	AD6	= IF(AB7<0,AB7*-1,0)
This cell calculates the total number of demanded items that were not filled by the purchase and it will be used to calculate the fill rate of the model.		

Table 19. Description of the Spreadsheet used with the genetic algorithms..

APPENDIX C. COMPARISON OF OUTPUT TABLES

GRADE	Demand Frequency	Demand Popularity	Demand Regularity	Navy Popularity	Criticality	Planned Program Requirement	Navy Priority
9	91	223	311	761	309	-	586
7	485	-	-	474	549	-	609
6	-	323	-	633	355	-	-
5	-	-	337	-	361	1236	-
4	667	-	-	1132	265	-	988
3	-	-	-	-	247	-	793
2	1757	1036	1323	-	372	-	-
1	-	1418	1029	-	542	-	-
0	-	-	-	-	-	1764	-
TOTAL	3000	3000	3000	3000	3000	3000	3000

Table 20. Frequency of Occurrences Per Parameter and Per Grade for the 3,000 Items Sample.

1998

GRADE	SPAADA	SBMA	EVOLVER – Optimal
9	9 – 90.11%	11 – 87.91%	9 – 90.11%
7	50 – 89.69%	70 – 85.57%	53 – 89.07%
4	164 – 75.41%	101 – 84.86%	133 – 80,06%
2	856 – 51.28%	240 – 86.34%	764 – 56.52%

1999

GRADES	SPAADA	SBMA	Modified SPAADA
9	2 – 97.80%	2– 97.80%	2– 97.80%
7	49 – 89.89%	52 – 89.28%	55 – 88.66%
4	157 – 76.46%	70 – 89.50%	138 – 79.31%
2	898 – 48.89%	218 – 87.59%	758 – 56.86%

2000

GRADES	SPAADA	SBMA	Modified SPAADA
9	7 – 92.31%	6 – 93.41%	7 – 92.31%
7	42 – 91.34%	45 – 90.72%	48 – 90.10%
4	174 – 73.91%	64 – 90.40%	138 – 79.31%
2	1073 – 38.93%	204 – 88.39%	852 – 51.51%

Table 21. Number of Backorders and Service Level[2] for the Parameter Demand's Frequency.

[2] The service levels are calculated following these steps: 1) Divide the number of backorders per grade and per parameter by the total number of items in that grade and in that parameter; 2) Diminish from 1 the number found in this division: SL = 1 – (Nr. of BO/total number of items in that grade), where SL is Service Level and BO is Backorders.

1998

GRADES	SPAADA	SBMA	Modified SPAADA
9	28 – 87.44%	38 – 82.96%	27 – 87.89%
6	29 – 91.02%	44 – 86.34%	29 – 91.02%
2	292 – 71.81%	150 – 85.52%	230 – 77.80%
1	730 – 48.52%	190 – 86.60%	673 – 52.54%

1999

GRADES	SPAADA	SBMA	Modified SPAADA
9	30 – 86.55%	27 – 87.89%	44 – 80.27%
6	19 – 94.12%	19 – 94.12%	20 – 93.81%
2	287 – 72.30%	120 – 88.42%	246 – 76.25%
1	770 – 45.70%	176 – 87.59%	643 – 54.65%

2000

GRADES	SPAADA	SBMA	Modified SPAADA
9	32 – 85.65%	27 – 87.89%	43 – 80.72%
6	27 – 91.64%	28 – 91.33%	28 – 91.33%
2	320 – 69.11%	106 – 89.77%	252 – 75.68%
1	917 – 35.33%	158 – 88.86%	722 – 49.08%

Table 22. Number of Backorders and Service Level for the Parameter Demand's Popularity.

1998

GRADES	SPAADA	SBMA	Modified SPAADA
9	25 – 91.96%	38 – 87.78%	25 – 91.96%
5	44 – 86.94%	54 – 83.98%	40 – 88.13%
2	479 – 63.79%	190 – 85.64%	373 – 71.81%
1	531 – 48.40%	140 – 86.39%	521 – 49.34%

1999

GRADES	SPAADA	SBMA	Modified SPAADA
9	20 – 93.57%	23 – 92.60%	20 – 93.57%
5	31 – 90.80%	34 – 89.91%	26 – 92.28%
2	476 – 64.02%	158 – 88.06%	380 – 71.28%
1	579 – 43.73%	127 – 87.66%	527 – 48.79%

2000

GRADES	SPAADA	SBMA	Modified SPAADA
9	23 – 92.60%	25 – 91.96%	23 – 92.60%
5	30 – 91.10%	33 – 90.21%	23 – 93.18%
2	560 – 57.67%	147 – 88.89%	403 – 69.54%
1	683 – 33.62%	114 – 88.92%	596 – 42.08%

Table 23. Number of Backorders and Service Level for the Parameter Demand's Regularity.

<u>1998</u>

GRADES	SPAADA	SBMA	Modified SPAADA
9	192 – 74.77%	117 – 84.63%	115 – 84.89%
7	112 – 76.37%	51 – 89.24%	83 – 82.49%
6	252 – 60.19%	100 – 84.20%	208 – 67.14%
4	523 – 53.80%	154 – 86.40%	553 – 51.15%

<u>1999</u>

GRADES	SPAADA	SBMA	Modified SPAADA
9	179 – 76.48%	79 – 89.62%	106 – 86.07%
7	123 – 74.05%	49 – 89.66%	100 – 78.90%
6	263 – 58.45%	74 – 88.31%	212 – 66.51%
4	546 – 51.77%	145 – 87.19%	535 – 52.74%

<u>2000</u>

GRADES	SPAADA	SBMA	Modified SPAADA
9	213 – 72.01%	88 – 88.43%	118 – 84.49%
7	140 – 70.46%	48 – 89.87%	106 – 77.64%
6	295 – 53.40%	57 – 91.00%	210 – 66.82%
4	648 – 42.76%	126 – 88.86%	611 – 46.02%

Table 24. Number of Backorders and Service Level for the Parameter Navy’s Popularity.

1998

GRADES	SPAADA	SBMA	Modified SPAADA
9	41 – 86.73%	41 – 86.73%	52 – 83.17%
7	111 – 79.78%	70 – 87.25%	114 – 79.23%
6	95 – 73.24%	53 – 85.07%	77 – 78.31%
5	135 – 62.61%	61 – 83.10%	119 – 67.04%
4	97 – 63.40%	36 – 86.42%	75 – 71.70%
3	106 – 57.09%	32 – 87.04%	89 – 63.97%
2	197 – 48.39%	62 – 83.33%	168 – 54.84%
1	297 – 45.20%	67 – 87.64%	265 – 51.11%

1999

GRADES	SPAADA	SBMA	Modified SPAADA
9	38 - 87.70%	34 – 89.00%	33 – 89.32%
7	119 – 78.32%	61 – 88.89%	90 – 83.61%
6	102 – 71.27%	37 – 89.58%	70 – 80.28%
5	129 – 64.27%	46 – 87.26%	101 – 72.02%
4	93 – 64.91%	23 – 91.32%	74 – 72.08%
3	112 – 54.25%	28 – 88.66%	101 – 59.11%
2	201 – 45.97%	49 – 86.93%	184 – 50.54%
1	312 – 42.44%	64 – 88.19%	300 – 44.65%

2000

GRADES	SPAADA	SBMA	Modified SPAADA
9	28 – 90.94%	32 – 89.64%	20 – 93.53%
7	145 – 73.59%	60 – 89.07%	92 – 83.24%
6	116 – 67.32%	34 – 90.42%	72 – 79.72%
5	163 – 54.85%	40 – 88.92%	115 – 68.14%
4	125 – 52.83%	31 – 88.30%	96 – 63.77%
3	133 – 46.15%	24 – 90.28%	109 – 55.87%
2	227 – 38.98%	41 – 88.98%	205 – 44.89%
1	359 – 33.76%	57 – 89.48%	336 – 38.00%

Table 25. Number of Backorders and Service Level for the Parameter Criticality.

1998

GRADES	SPAADA	SBMA	Modified SPAADA
O	694 – 60.66%	233 – 86.79%	612 – 65.31%
5	385 – 68.85%	189 – 84.71%	347 – 71.92%

1999

GRADES	SPAADA	SBMA	Modified SPAADA
O	732 – 58.50%	206 – 88.32%	624 – 64.63%
5	374 – 69.74%	136 – 89.00%	329 – 73.38%

2000

GRADES	SPAADA	SBMA	Modified SPAADA
O	855 – 51.53%	197 – 88.83%	673 – 61.85%
5	441 – 64.32%	122 – 90.13%	372 – 69.90%

Table 26. Number of Backorders and Service Level for the Parameter Planned Program Requirements (PPR).

1998

GRADES	SPAADA	SBMA	Modified SPAADA
9	138 – 76.45%	81 – 86.18%	118 – 79.86%
7	178 – 70.77%	90 – 85.22%	162 – 73.40%
4	399 – 59.62%	133 – 86.54%	362 – 63.36%
3	352 – 55.61%	116 – 85.37%	308 – 61.16%

1999

GRADES	SPAADA	SBMA	Modified SPAADA
9	137 – 76.62%	73 – 87.54%	121 – 79.35%
7	182 – 70.11%	69 – 88.67%	168 – 72.41%
4	406 – 58.91%	114 – 88.46%	346 – 64.98%
3	368 – 53.59%	84 – 89.41%	309 – 61.03%

2000

GRADES	SPAADA	SBMA	Modified SPAADA
9	148 – 74.74%	63 – 89.25%	118 – 79.86%
7	212 – 65.19%	64 – 89.49%	172 – 71.76%
4	493 – 50.10%	107 – 89.17%	399 – 59.62%
3	429 – 45.90%	82 – 89.66%	345 – 56.49%

Table 27. Number of Backorders and Service Level for the Parameter Navy's Priority.

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APPENDIX D. COMPARISON OF OUTPUT TABLES AFTER INTRODUCING STOCK TO THE MODELS

GRADE	Demand's Frequency	Demand's Popularity	Demand's Regularity	Navy's Popularity	Criticality	Planned Program Requirement	Navy's Priority
9	91	223	311	761	309	-	586
7	485	-	-	474	549	-	609
6	-	323	-	633	355	-	-
5	-	-	337	-	361	1236	-
4	667	-	-	1132	265	-	988
3	-	-	-	-	247	-	793
2	1757	1036	1323	-	372	-	-
1	-	1418	1029	-	542	-	-
0	-	-	-	-	-	1764	-
TOTAL	3000	3000	3000	3000	3000	3000	3000

Table 28. Frequency of Occurrences Per Parameter and Per Grade for the 3,000 Items Sample.

1999

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	1 – 98.90%	1 – 98.90%	1 – 98.90%
7	39 – 91.96%	31 – 93.61%	37 – 92.37%
4	101 – 84.86%	40 – 94.00%	74 – 88.90%
2	684 – 61.07%	138- 92.15%	573 – 67.39%

2000

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	6 – 93.41%	1 – 98.30%	6 – 93.41%
7	33 – 93.20%	17 – 96.49%	31 – 93.61%
4	97 – 85.46%	26 – 96.10%	45 – 93.25%
2	753 – 57.14%	96 – 94.54%	588 – 66.53%

Table 29. Number of Backorders and Service Level[3] for the Parameter Demand's Frequency When Stock Is Carried Over from One Year to the Next.

[3] The service levels are calculate following these steps: 1) Divide the number of backorders per grade and per parameter by the total number of items in that grade and in that parameter; 2) Diminish from 1 the number found in this division: SL = 1 – (Nr. of BO / total number of items in that grade), where SL is service level and BO is backorders.

1999

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	21 - 90.58%	14 – 93.72%	28 – 87.44%
6	17 - 94.74%	10 – 96.90%	17 – 94.74%
2	208 - 79.92%	72 – 93.05%	164 – 84.17%
1	579 - 59.17%	114 – 91.96%	476 – 66.43%

2000

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	20 – 91.03%	10 – 95.52%	29 – 87.00%
6	23 – 92.88%	13 – 95.98%	23 – 92.88%
2	211 – 79.63%	39 – 96.24%	127 – 87.74%
1	635 – 55.22%	78 – 94.50%	491 – 65.37%

Table 30. Number of Backorders and Service Level for the Parameter Demand's Popularity When Stock Is Carried Over from One Year to the Next.

1999

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	121 – 84.10%	47 – 93.82%	67 – 91.20%
7	89 – 81.22%	27 – 94.30%	68 – 85.65%
6	199 – 68.56%	46 – 92.72%	158 – 75.04%
4	416 – 63.25%	90 – 92.05%	392 – 65.37%

2000

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	139 – 81.73%	31 – 95.92%	59 – 92.25%
7	93 – 80.38%	25 – 94.73%	49 – 89.66%
6	199 – 68.56%	25 – 96.05%	133 – 78.99%
4	458 – 59.545	59 – 94.79%	429 – 62.10%

Table 31. Number of Backorders and Service Level for the Parameter Navy's Popularity When Stock Is Carried Over from One Year to the Next.

1999

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	92 – 84.30%	38 – 93.52%	48 – 91.81%
7	136 – 77.67%	41 – 93.27%	53 – 91.30%
4	302 – 69.43%	74 – 92.51%	270 – 72.67%
3	286 – 63.93%	56 – 92.94%	303 – 61.79%

2000

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	83 – 85.84%	28 – 95.22%	28 – 95.22%
7	137 – 77.50%	32 – 94.75%	41 – 93.27%
4	344 – 65.18%	45 – 95.44%	267 – 72.98%
3	315 – 60.28%	34 – 95.71%	323 - 59.27%

Table 32. Number of Backorders and Service Level for the Parameter Priority of the Supply System When Stock Is Carried Over from One Year to the Next.

1999

GRADES	SPAADA	SBMA	MODIFIED SPAADA
0	567 – 54.13%	135 – 89.08%	440 – 64.40%
5	258 – 85.37%	75 – 95.75%	245 – 86.11%

2000

GRADES	SPAADA	SBMA	MODIFIED SPAADA
0	610 – 50.65%	93 – 92.48%	430 – 65.21%
5	279 – 84.18%	47 – 97.34%	240 – 86.39%

Table 33. Number of Backorders and Service Level for the Parameter Planned Program Requirements When Stock Is Carried Over from One Year to the Next.

1999

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	14 – 95.50%	10 – 96.78%	14 – 95.50%
5	22 – 93.47%	16 – 95.25%	22 – 93.47%
2	347 – 73.77%	106 – 91.99%	278 – 78.99%
1	442 – 57.05%	78 – 92.42%	371 – 63.95%

2000

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	20 – 93.57%	10 – 96.78%	20 – 93.57%
5	22 – 93.47%	12 – 96.44%	22 – 93.47%
2	364 – 72.49%	63 – 95.24%	239 – 77.32%
1	483 – 53.06%	55 – 94.66%	389 – 52.48%

Table 34. Number of Backorders and Service Level for the Parameter Demand's Regularity When Stock Is Carried Over from One Year to the Next.

1999

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	22 – 92.88%	20 – 93.53%	27 – 91.26%
7	58 – 89.44%	44 – 91.99%	97 – 82.33%
6	53 – 85.07%	23 – 93.52%	69 – 80.56%
5	84 – 76.73%	23 – 93.63%	85 – 76.45%
4	68 – 74.34%	14 – 94.72%	50 – 81.13%
3	94 – 61.94%	13 – 94.74%	66 – 73.28%
2	171 – 54.03%	34 – 90.86%	114 – 69.35%
1	275 – 49.26%	39 – 92.80%	177 – 67.34%

2000

GRADES	SPAADA	SBMA	MODIFIED SPAADA
9	16 – 94.82%	16 – 94.82%	29 – 90.61%
7	47 – 91.44%	27 – 95.08%	105 – 80.87%
6	48 – 86.48%	13 – 96.33%	70 – 80.28%
5	94 – 73.96%	16 – 95.57%	89 – 75.35%
4	86 – 67.58%	18 – 93.21%	66 – 75.09%
3	101 – 59.11%	11 – 95.55%	51 – 79.35%
2	188 – 49.46%	14 – 96.24%	99 – 73.39%
1	309 – 42.99%	25 – 95.39%	161 – 70.30%

Table 35. Number of Backorders and Service Level for the Parameter Criticality When Stock Is Carried Over from One Year to the Next.

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